The Impact of Very High Frequency Surface Reverberation on Coherent Acoustic Propagation and Modeling

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LONG-TERM GOALS

The long-term science objective is to develop a physical model of high-frequency scattering of underwater acoustic signals from the sea surface under a range of wind-driven conditions. The model will focus on signal coherence, and second-order amplitude and Doppler statistics.

The scattering of sound from the sea surface is important for the operation of underwater sonar and underwater acoustic communications systems. Studies of low to mid-frequency surface reverberation have a long history, but studies of very high frequency (>300 kHz) surface scattering in the literature are rare. The physics of very high frequency (VHF) scattering is expected to be strongly dependent on wind speed, which controls surface roughness and wave breaking, which inject bubbles into the ocean. The amplitude, Doppler spread and temporal coherence of VHF scattering is important for the performance of high frequency sonars and underwater communications systems in operating scenarios where energy from the sea surface cannot be screened.

OBJECTIVES

There are two primary objectives. The first is to study the underlying relationship between the amplitude, Doppler and coherence of VHF acoustic signals scattered from a rough ocean surface driven by a range of wind speeds. The second is to investigate the impact of surface scattered VHF acoustic energy on coherent VHF underwater acoustic communications. Recent work by Dr. James Preisig at WHOI has shown that the optimal spacing of receiver elements in a vertical communications array depends on the vertical wave number spectrum of the acoustic field in the medium frequency regime, and surface scattering is a primary determinant of this spectrum. However, in the VHF regime increased surface bounce losses may increase the importance of other water column physics, such as internal scattering by turbulence, on the angular spread of the received field. Addressing the relative importance of surface versus water column scattering will be important in the design of optimal arrays for VHF systems.

In addition, the physics of Doppler statistics, which scales with frequency, and scattering from small scale surface waves, which is dominated by ultra-gravity and capillary waves in the VHF regime are expected to be quite different from those encountered at low to midrange frequencies. We are proposing a series of laboratory and field experiments to quantify these different physical scattering regimes.

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APPROACH

The technical approach is divided between field and laboratory campaigns and propagation and surface scattering model development. We are only 7 months into this 36 month project, and work in this initial phase has focused on laboratory measurements of high frequency surface scattering and simulations of the scattered signal. These experiments were done at a transmission frequency of 300 kHz. Arrangements are being made with Dr. James Preisig at WHOI to acquire 600 kHz transducer arrays, which will be more in line with the high frequency communications band to be used in the field. These will be used to in higher frequency experiments in the wind-wave simulator, and in 30 m deep water off La Jolla Shores Beach.

WORK COMPLETED

Initial experiments were conducted in the wind-wave channel in the Hydraulics Laboratory at SIO. This ocean wave simulator is 40 m long, 2.4 m wide, and filled with seawater to a depth of 1.25 m. Surface waves can be generated with a hydraulic paddle at one end of the tank and winds up to 15 ms^{-1} can be generated in the headspace above the water surface. The data reported here were taken with a stationary paddle and winds in the range 0 – 6 ms^{-1}.

The geometry for the experiment is shown in Fig. 1. A series of 1.5 cycle pulse signals centered on 300 kHz were transmitted as the wind in the channel was slowly increased. Wind speed was monitored with a vane anemometer mounted in the simulator headspace. Surface wave spectra were continuously measured with a wire wave gauge placed slightly downstream of the acoustic transducers. The transducers themselves were placed in the middle of the channel, allowing bottom and side-wall reflected arrivals to be time-gated out of the received signal. Data was acquired with a 4-channel, 16 bit data acquisition system sampling at 4 MHz.

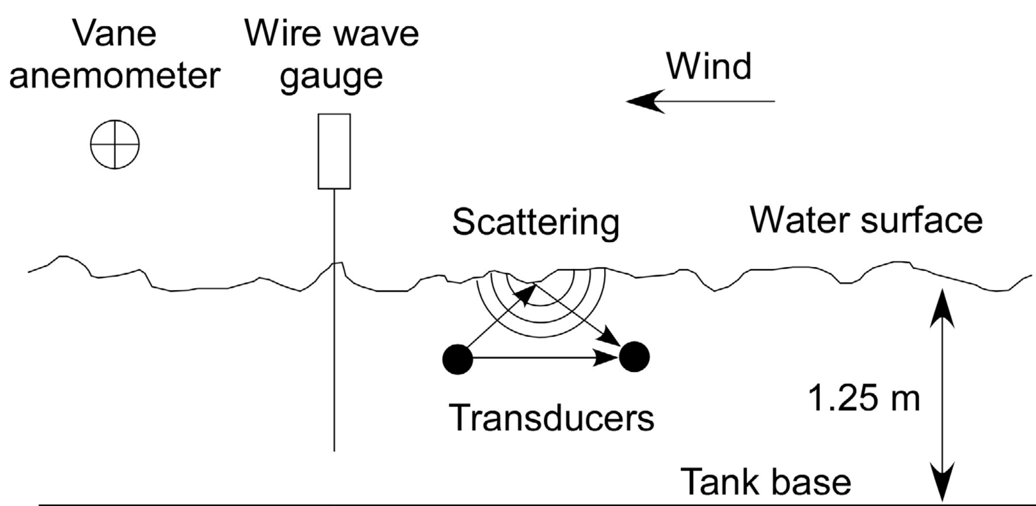

Figure 1. Geometry for the high frequency scattering experiment in the wind-wave simulator.

A summary of the dataset is shown in Fig.2. Surface-scattered energy is perfectly regular until the wind speed reaches approximately 2 ms^{-1}. At this speed, there is sufficient wind shear stress to generate surface waves, resulting in variability in arrival amplitude. A count of the intensifications in the 5th and 6th time

series from the top pf the right panel shows that surface waves with a frequency of approximately 6 Hz are scattering the sound, in good agreement with the frequency of surface waves in the center panel 2000 seconds into the run.

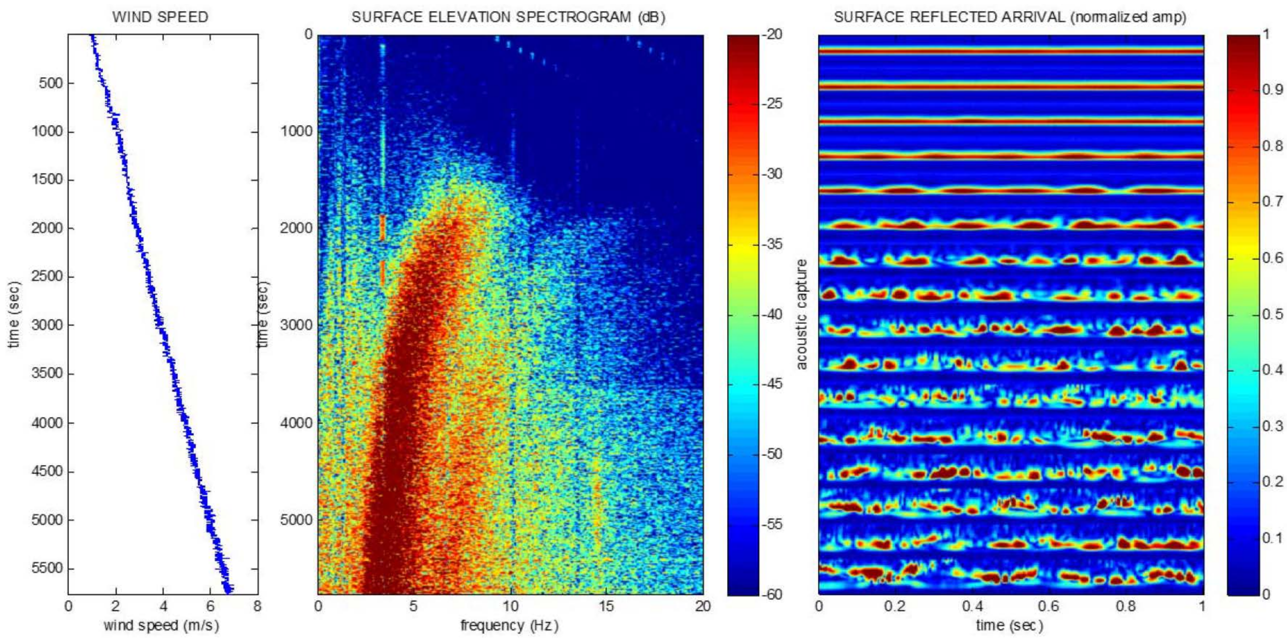

Figure 2. Summary of the high frequency scattering experiment in the wind-wave simulator. Left hand panel: Wind speed versus time in seconds. Center panel: A spectrogram of the surface elevation spectrum in dB re 1 m^2 Hz^{-1} versus time and frequency. The vertical bands in the spectrogram are artifacts caused by gound loop noise introduced by the fan. Wind shear stress starts to generate surface waves at around 2 ms^{-1} wind speed. Right panel: Time series of surface-scattered acoustic arrival amplitude, normalized to direct arrival amplitude, plotted over a 1 s interval. Each horizontal band corresponds to a segment of transmission at the corresponding time on the left panel vertical axis. Fluctuations in arrival amplitude and delay increase with increasing wind speed.

The surface scattering data has been analyzed into distributions of arrival intensity, and these are shown in Figure 3. The distributions are not normalized, so they integrate to the total number of arrivals observed over the sampling interval, which was constant for all the intervals. The narrow, peaked distributions correspond to wind speeds less than 2 ms^{-1}, for which there was no surface wave activity. As surface wave activity increases with increasing wind speed, arrival intensity becomes spread and then saturates with a fixed distribution. The transition from unsaturated to saturated scattering statistics occurs at a wind speed of approximately 3 ms^{-1}. The reasons for the saturation are discussed in the results section.

The second component of work completed are simulations of high frequency scattering. The calculations are based in direct numerical integral of the Helmholtz-Kirchhoff scattering integral. Surface elevation time series were simulated using a Pearson-Moskowitz gravity wave spectrum for a 5 ms^{-1} wind speed, high-pass filtered at 0.8 Hz. This simulation includes lower frequency waves than were present in the wind-wave simulator, but which will be present for transmissions at sea.

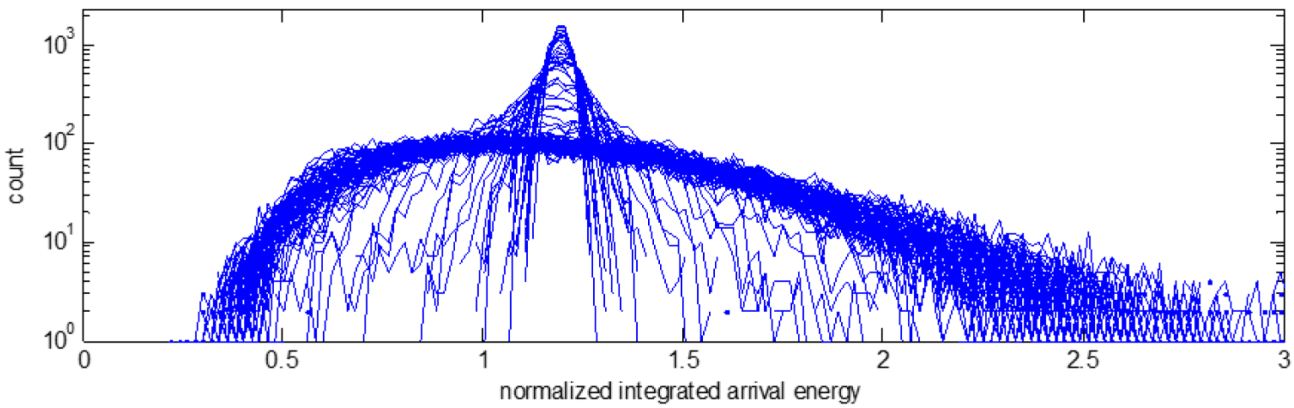

Figure 3. Distributions of normalized, integrated arrival energy as a function of time. 96 runs at different wind speeds are superposed. Values of normalized arrival eneergy greater than 1 correspond to energy focused beyond the direct arrival energy. Energies as high as 3 and as low as 0.4 can be seen. The offset of the narrow distributions for low wind speeds from a value of 1 is a due to the directionality of the transducers, which was not compensated for.

An example of the simulations are shown in Figure 4. Intensifications and time delays due to surface waves are evident. This computational capacity is being developed to simulate communications signal transmissions in the presenceof signal scattered by the surface, and is not yet validated against laboratory or field studies.

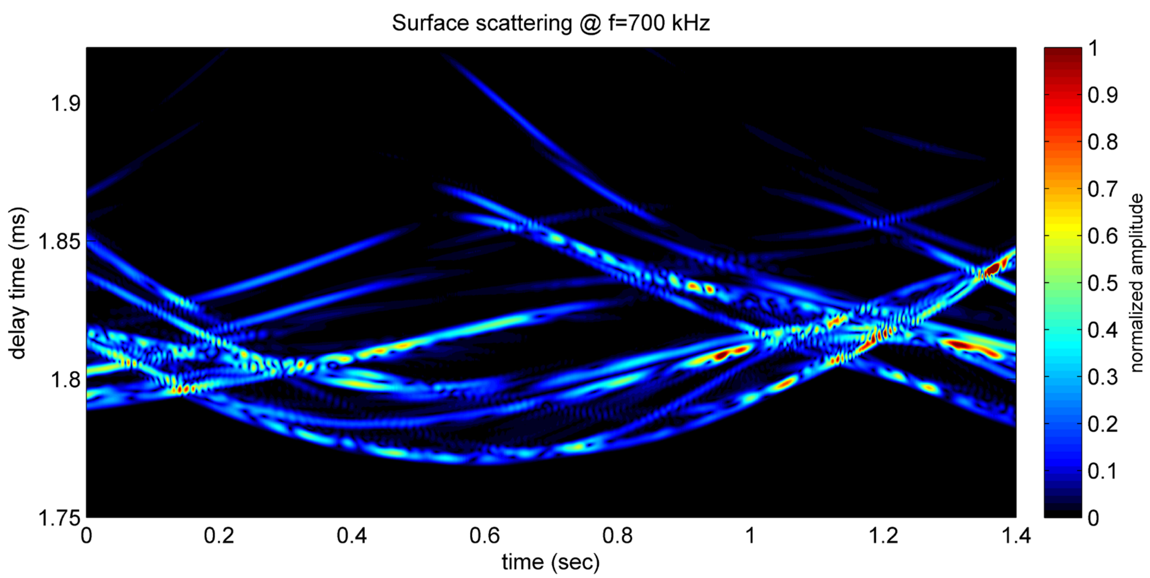

Figure 4. A example of model calculations of 700 kHz pulses scattered from the sea surface. The source-receiver seperation is 2.5 m and the source and receiver depths are 0.5 m. This geometry yields a grazing angle with the surface of 22^o.

RESULTS

Some important conclusions can be drawn from the wind-wave simulator experiments. The arrival amplitude statistics are controlled by the curvature of the sea surface[1], whereas arrival delay statistics

are controlled by the largest amplitude component of the wave field. As wind speed increases, the part of the surface wave spectrum leading to amplitude fluctations saturates, and the amplitude fluctuations also saturate (see Fig. 3). In contrast, the fluctuations in arrival delay do not saturate, because increases in wind speed result in ever increasing wave amplitude at lower frequencies. This is shown in Fig. 5 by the contrast in behavior of the arrival energy fluctuations (blue curve) versus arrival time fluctuations (green curve).

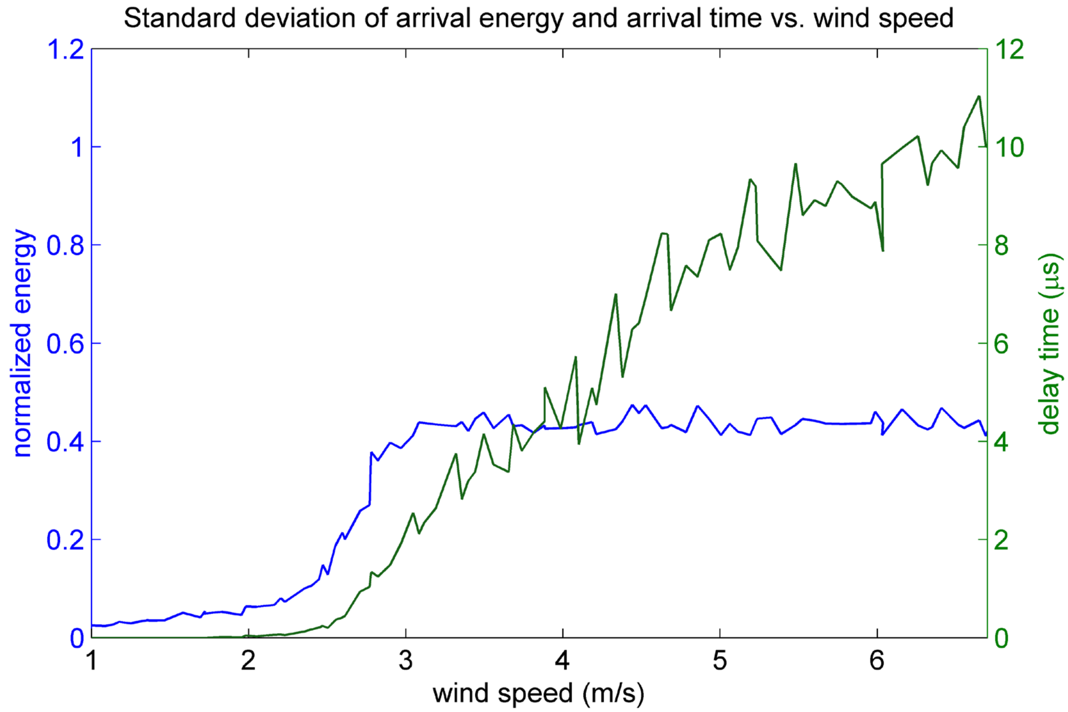

Figure 5. Standard deviation in normalized arrival energy (blue line) and arrival delay (green line) versus wind speed. The saturation of variability in arrival at 3 ms^{-1} is in constrast to arrival delay, which continues to increase with increasing wind speed.

Extralolation to the ocean suggests that amplitude fluctuations linked to surface waves will be significant at wind speeds as low as 2 ms^{-1}. Unfortunately, increasing the wind speed further does not help reduce the surface-scattered signal as the amplitude statistics saturate and remain constant (see the plateau in the blue curve of Fig. 5). At moderate to high wind speeds (> 8 ms^{-1}) scattering by bubbles may screen the surface, creating a more benign underwater communications channel. Whether or not this is the case will be tested in the wind-wave simulator, which can be set up to simulate wave breaking. A final variable that is yet to be measured is the ambient noise radiated by breaking waves in the frequency band 500 kHz – 1000 kHz.

IMPACT/APPLICATIONS

This work has application to the design and operation of high frequency underwater communications systems operated near the sea surface. The results from these experiments and simulations will be applied to the design of signal processing algorithms to improve the performance of underwater communications systems in the presence of surface reverberation.

RELATED PROJECTS

Related ONR contracts are N00014-14C-0230 and N00014-14P-1063.

REFERENCES

Deane, Grant B., et al. "Deterministic forward scatter from surface gravity waves." J. Acoust. Soc. Am., **132**, 3673-3686, 2012.

PUBLICATIONS

Walstead, S. P. and G. B. Deane, "Resonstructing surface wave profiles from reflected acoustic pulses using multiple receivers," J. Acoust. Soc. Am., **133**, 2597-2611, 2013 [published, refereed].